PROCEEDINGS OF SCIENCE

# MMHT Updates, LHC jets and $\alpha_S$

**R.S. Thorne***
*Department of Physics and Astronomy,*
*University College London, WC1E 6BT, UK*
*E-mail:* robert.thorne@ucl.ac.uk

**L.A. Harland-Lang**
*Department of Physics and Astronomy,*
*University College London, WC1E 6BT, UK*
*E-mail:* l.harland-lang@ucl.ac.uk

**A.D. Martin**
*Institute for Particle Physics Phenomenology,*
*University of Durham, DH1 3LE, UK*
*E-mail:* A.D.Martin@durham.ac.uk

We summarise the effects of including jet data from the LHC in the MMHT PDF extraction. We also present the latest results on the preferred value of the strong coupling $\alpha_S(M_Z^2)$ in a number of fit variations. The best current value with all new data is $\alpha_S(M_Z^2) = 0.1176$.

*XXVI International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2018)*
*16-20 April 2018*
*Kobe, Japan*

*Speaker.

The MMHT2014 parton distributions [1] included a variety of LHC data in their determination. However, at NNLO they did not include jet data from the LHC due to the lack of knowledge of the complete cross section at this order. This calculation is now complete [2], so consequently jet data can be included in a MMHT update. A study of the inclusion of jet data has been presented in [3], but we will present a brief summary here. We will also present an update on the determination of the best-fit value of $\alpha_S(M_Z^2)$. We begin by noting that soon after the publication of the MMHT PDFs we also studied the effect of including the final HERA total cross section measurements [4], noting only minor changes in the central values and reductions in uncertainties of up to 10% [5]. We will start from the PDFs in [5] when considering the effect of further updates in this account.

## 1. LHC jet data

We include the full range of 7 TeV ATLAS [6] and CMS [7, 8] inclusive jet data at both NLO and NNLO. The fit works well for CMS data but for the ATLAS data we find that we cannot simultaneously fit data in all the rapidity bins. There is a mismatch in one bin which is different in form to neighbouring bins constraining PDFs of similar $x$ and $Q^2$. This qualitative conclusion is independent of jet radius $R$, choice of scale or inclusion of NNLO corrections. This problem led us to consider an exercise on decorrelating uncertainties, i.e. we investigated the effect on the $\chi^2$ of the fit to ATLAS jet data when decorrelating a particular uncertainty source. We considered making each source independent between the 6 rapidity bins. For some sources we found very significant improvement, particularly from decorrelating source jes21. In fact, with correlations between rapidity bins relaxed for just two sources of systematics we obtained an improvement in fit quality from $\chi^2/N_{pts} > 300/140$ to $\chi^2/N_{pts} = 178/140 = 1.27$. (This was followed by a more extensive decorrelation study [9] by ATLAS for the 8 TeV jet data.) We see similar results on the fit quality improvement with decorrelation using the new NNLO results on cross sections as at NLO, though generally the fit quality is better at NNLO. However, the fit quality is also very dependent on the scales used in the calculation and on jet radius. The change in the gluon distribution compared to the baseline when ATLAS jet data are included is shown in Fig. 1. The gluon preferred is a little softer at high $x$ when the jet data are included, and crucially, is not very sensitive at all to whether the correlations are treated in the default manner, or to the improvement in $\chi^2$ is obtained by decorrelating two sources (partial decorrelation – pd). When all sources of correlated uncertainty are decorrelated between different rapidity bins (full decorrelation – fd) the gluon is different, and rather closer to the baseline.

When jet data from both ATLAS and CMS are included, the picture is the same, i.e. CMS data are well fit, and ATLAS data fit well when two uncertainty sources are decorrelated, but the gluon remains insensitive to this decorrelation. The net effect on the gluon is shown in Fig.2, and is similar to that for the inclusion of only ATLAS data. There is some mild tension between ATLAS and CMS data, with the latter preferring a larger high-$x$ gluon, but the gluon more closely follows that in the ATLAS only fit. We see from Fig. 2 that the gluon is largely insensitive to the scale choice or jet radius, even though the fit quality and shifts between data and theory using the correlated uncertainties do depend rather more on these. The inclusion of the LHC jet data reduces the uncertainty on the gluon a little as shown in Fig. 3.



PoS(DIS2018)030

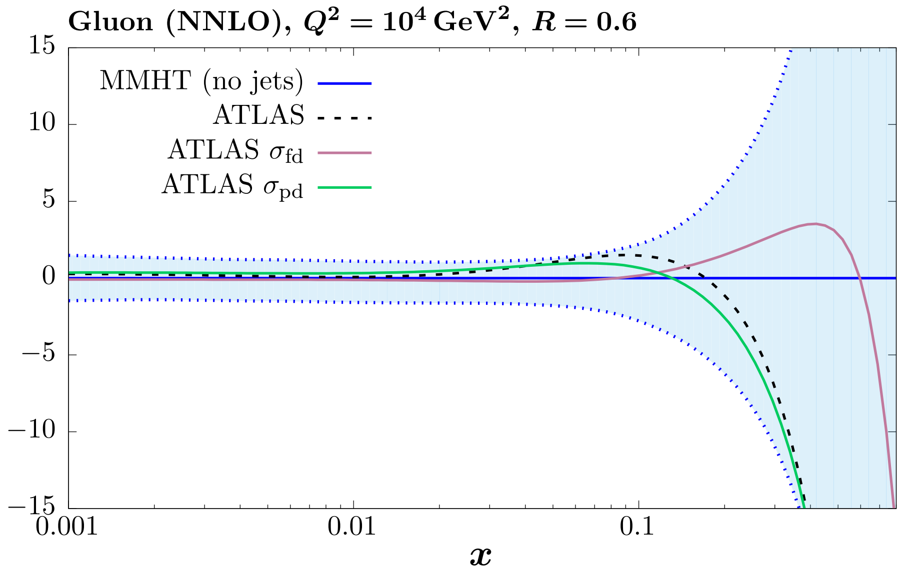


**Figure 1:** The dependence of the gluon on the treatment of correlated uncertainties at NNLO when ATLAS jet data are included.

For the results that we show we have omitted the Tevatron jet data, since we do not have the NNLO corrections for these. Results when they are included using the long-known threshold approximation to NNLO are shown in detail in [3]. The main result is a slight tension between LHC and Tevatron jet data, with a slightly harder high-$x$ gluon in the combined fit, and a slight further reduction in the gluon uncertainty.

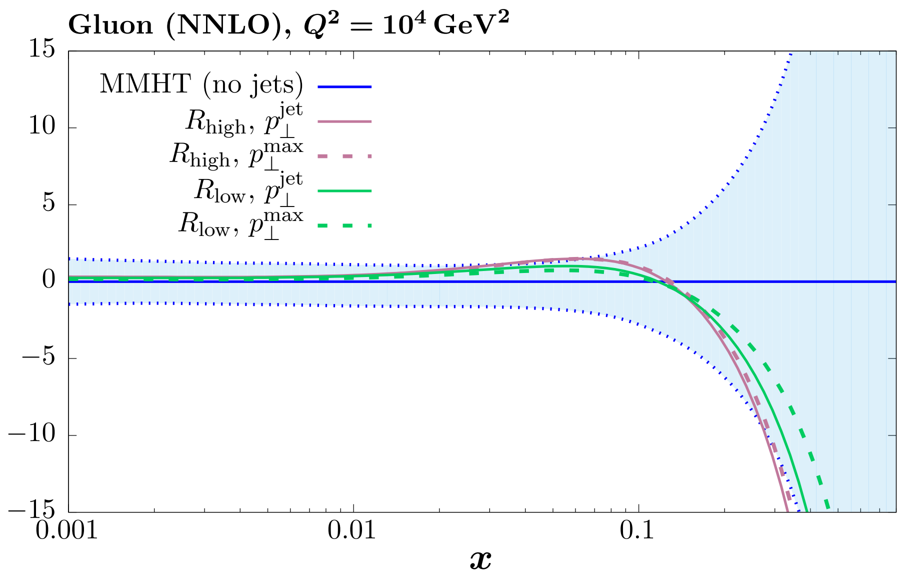


**Figure 2:** The gluon at NNLO for different scale choices and values of jet radius when both ATLAS and CMS jet data are included in the fit.

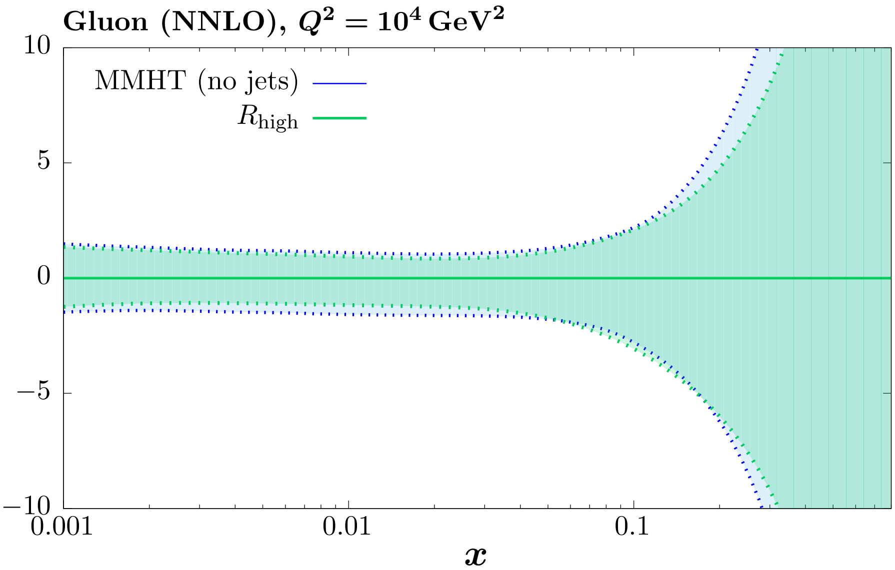


**Figure 3:** The uncertainty on the gluon at NNLO when ATLAS and CMS jet data are fit.

## 2. $\alpha_S$ Determination

For MMHT2014 the best fit $\alpha_S(M_Z^2) = 0.1172 \pm 0.0013$ (or $\alpha_S(M_Z^2) = 0.1178$ when the world average is added as data point) at NNLO, and a detailed study of PDF versus $\alpha_S$ dependence was presented in [10]. With the addition of 8 TeV data on $\sigma_{\bar{t}t}$ and final HERA data this value increased marginally to $\alpha_S(M_Z^2) = 0.118$ [11]. When we consider the further addition of the LHC jet data, and removal of the Tevatron jet data, the best fit gives a lower value of $\alpha_S(M_Z^2) = 0.1164$. A different shape high and medium $x$ gluon in this fit when $\alpha_S$ is left free leads to a larger coupling. However, when Tevatron jet data are again included then we get an increase to $\alpha_S(M_Z^2) = 0.1173$.

We also consider the effect of adding in all of the newer $W, Z$ data from ATLAS,CMS, LHCb and the Tevatron data [12, 13, 14, 15, 16, 17, 18] already considered in previous MMHT updates [11]. Including these data but not the LHC jet data we obtain $\alpha_S(M_Z^2) = 0.1180$. Additionally including newer LHC jet data leads to $\alpha_S(M_Z^2) = 0.1176$ (or 0.1178 for ATLAS jet data fitted with full decorrelation of uncertainties). Therefore, recent Drell-Yan type data stabilises the $\alpha_S(M_Z^2)$ value slightly. The variation of $\chi^2$ with $\alpha_S(M_Z^2)$ for these fits is shown in Fig. 4. Our best value of $\alpha_S(M_Z^2) = 0.1176$, obtained using the maximal set of data, can be compared to the slightly higher recent determination of $\alpha_S(M_Z^2) = 0.1185$ in [19], which is consistent within uncertainties, and the rather lower value of $\alpha_S(M_Z^2) = 0.1147$ in [20].

In Table 1 we also show the fit quality when including all our recent LHC data updates in the fit at NNLO (for the default $\alpha_S(M_Z^2) = 0.118$) both without and with the LHC jet data in the fit. For the LHC jet data there is an increase $\Delta\chi^2 = 2$ when the other recent LHC data are also included simultaneously. Hence, one can see that there is no real tension between the LHC jet data and the recent LHC $W, Z$, and inclusive top-pair data. The slight deterioration in the global fit quality when the LHC jet data is included is partially due to some tension between this and the Tevatron jet data.

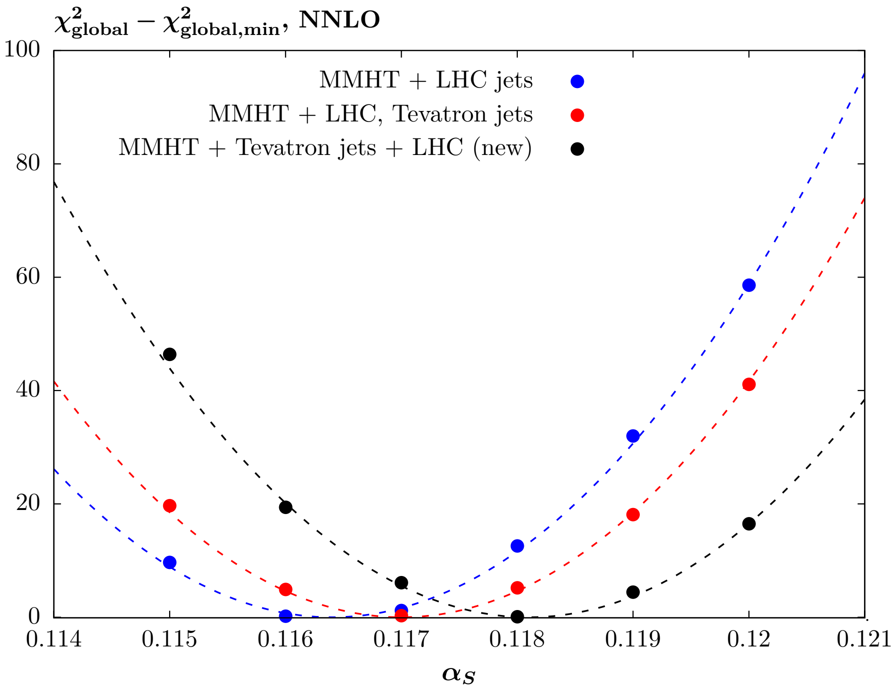


**Figure 4:** The variation of $\chi^2$ with $\alpha_S(M_Z^2)$ for updated PDF fits either without or with LHC jet data.

| | no. points | NNLO $\chi^2$ | NNLO $\chi^2_{\text{LHCjets}}$ |
|---|---|---|---|
| $\sigma_{t\bar{t}}$ Tevatron +CMS+ATLAS | 18 | 14.3 | 14.2 |
| LHCb 7 TeV $W+Z$ | 33 | 40.0 | 40.2 |
| LHCb 8 TeV $W+Z$ | 34 | 56.4 | 54.2 |
| LHCb 8TeV $e$ | 17 | 27.9 | 27.3 |
| CMS 8 TeV $W$ | 22 | 17.7 | 17.4 |
| CMS 7 TeV $W+c$ | 10 | 9.0 | 9.9 |
| D0 $e$ asymmetry | 13 | 24.2 | 26.9 |
| ATLAS 7 TeV $W,Z$ | 61 | 108.3 | 110.5 |
| total | 3466 | 3868 | 3881 |

**Table 1:** The $\chi^2$ for various data sets when the LHC jets data are omitted and included. The "total" does not include the LHC jet data.

## Acknowledgements

LHL thanks the Science and Technology Facilities Council (STFC) for support via grant awards ST/L000377/1 and ST/P004547/1. RST thanks the Science and Technology Facilities Council (STFC) for support via grant awards ST/L000377/1 and ST/P000274/1.

## References

[1] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, Eur. Phys. J. C **75** (2015) no.5, 204 doi:10.1140/epjc/s10052-015-3397-6 [arXiv:1412.3989 [hep-ph]].

[2] J. Currie, E. W. N. Glover and J. Pires, Phys. Rev. Lett. **118** (2017) no.7, 072002 doi:10.1103/PhysRevLett.118.072002 [arXiv:1611.01460 [hep-ph]].

[3] L. A. Harland-Lang, A. D. Martin and R. S. Thorne, Eur. Phys. J. C **78** (2018) no.3, 248 doi:10.1140/epjc/s10052-018-5710-7 [arXiv:1711.05757 [hep-ph]].

[4] H. Abramowicz *et al.* [H1 and ZEUS Collaborations], Eur. Phys. J. C **75** (2015) no.12, 580 doi:10.1140/epjc/s10052-015-3710-4 [arXiv:1506.06042 [hep-ex]].

[5] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, Eur. Phys. J. C **76** (2016) no.4, 186 doi:10.1140/epjc/s10052-016-4020-1 [arXiv:1601.03413 [hep-ph]].

[6] G. Aad *et al.* [ATLAS Collaboration], JHEP **1502** (2015) 153 Erratum: [JHEP **1509** (2015) 141] doi:10.1007/JHEP02(2015)153, 10.1007/JHEP09(2015)141 [arXiv:1410.8857 [hep-ex]].

[7] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Rev. D **87** (2013) no.11, 112002 Erratum: [Phys. Rev. D **87** (2013) no.11, 119902] doi:10.1103/PhysRevD.87.112002, 10.1103/PhysRevD.87.119902 [arXiv:1212.6660 [hep-ex]].

[8] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Rev. D **90** (2014) no.7, 072006 doi:10.1103/PhysRevD.90.072006 [arXiv:1406.0324 [hep-ex]].

[9] M. Aaboud *et al.* [ATLAS Collaboration], JHEP **1709** (2017) 020 doi:10.1007/JHEP09(2017)020 [arXiv:1706.03192 [hep-ex]].

[10] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, Eur. Phys. J. C **75** (2015) no.9, 435 doi:10.1140/epjc/s10052-015-3 630-3 [arXiv:1506.05682 [hep-ph]].

[11] R. S. Thorne, L. A. Harland-Lang and A. D. Martin, PoS DIS **2017** (2018) 202 doi:10.22323/1.297.0202 [arXiv:1708.00047 [hep-ph]].

[12] R. Aaij *et al.* [LHCb Collaboration], JHEP **1508** (2015) 039 doi:10.1007/JHEP08(2015)039 [arXiv:1505.07024 [hep-ex]].

[13] R. Aaij *et al.* [LHCb Collaboration], JHEP **1601** (2016) 155 doi:10.1007/JHEP01(2016)155 [arXiv:1511.08039 [hep-ex]].

[14] R. Aaij *et al.* [LHCb Collaboration], JHEP **1505** (2015) 109 doi:10.1007/JHEP05(2015)109 [arXiv:1503.00963 [hep-ex]].

[15] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1402** (2014) 013 doi:10.1007/JHEP02(2014)013 [arXiv:1310.1138 [hep-ex]].

[16] V. Khachatryan *et al.* [CMS Collaboration], Eur. Phys. J. C **76** (2016) no.8, 469 doi:10.1140/epjc/s10052-016-4293-4 [arXiv:1603.01803 [hep-ex]].

[17] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **91** (2015) no.3, 032007 Erratum: [Phys. Rev. D **91** (2015) no.7, 079901] doi:10.1103/PhysRevD.91.032007, 10.1103/PhysRevD.91.079901 [arXiv:1412.2862 [hep-ex]].

[18] M. Aaboud *et al.* [ATLAS Collaboration], Eur. Phys. J. C **77** (2017) no.6, 367 doi:10.1140/epjc/s10052-017-4911-9 [arXiv:1612.03016 [hep-ex]].

[19] R. D. Ball *et al.* [NNPDF Collaboration], Eur. Phys. J. C **78** (2018) no.5, 408 doi:10.1140/epjc/s10052-018-5897-7 [arXiv:1802.03398 [hep-ph]].

[20] S. Alekhin, J. Blümlein, S. Moch and R. Placakyte, Phys. Rev. D **96** (2017) no.1, 014011 doi:10.1103/PhysRevD.96.014011 [arXiv:1701.05838 [hep-ph]].